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N72-16519  
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**A 640 FT/SEC IMPACT TEST OF A TWO-FOOT DIAMETER MODEL  
NUCLEAR REACTOR CONTAINMENT SYSTEM WITHOUT FRACTURE**

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# ABSTRACT

An impact test was conducted on an 1142 pound - 2-foot diameter sphere model at the Holloman Sled Track in Alamogordo, New Mexico. This test is a part of a study to determine the feasibility of containing the fission products of a mobile reactor in an impact. The model simulated the reactor core, energy absorbing gamma shielding, neutron shielding and the containment vessel. It was impacted against an 18 000 pound reinforced concrete block. The model was significantly deformed and the concrete block demolished. No leaks were detected nor cracks observed in the model after impact.

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A 640 FT/SEC IMPACT TEST OF A TWO-FOOT DIAMETER MODEL  
NUCLEAR REACTOR CONTAINMENT SYSTEM WITHOUT FRACTURE

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SUMMARY

Future applications of nuclear energy may require the use of a mobile nuclear reactor. Fission products in mobile reactors must be contained with the same level of confidence as in stationary powerplants. One method for containing fission products in the event of an impact of a mobile reactor is to put the reactor in a containment vessel and design the containment vessel and its contents to absorb the impact energy without rupturing the containment vessel.

A previous set of five tests was conducted at Sandia Corporation on two-foot diameter mock-up models of a reactor containment vessel system. The models weighed from 350 to 1305 pounds. They were impacted at speeds from 241 to 580 feet per second. No leaks were detected nor cracks observed on any of the models after impact. Examination of the models indicated a potential for survival at impact speeds of 1000 feet per second.

A new series of tests were then planned with impact velocities up to 1000 ft/sec. The first model tested in this series was impacted at 640 ft/sec against an 18 000 pound reinforced concrete block. The model weighed 1142 pounds. It simulated the reactor core, energy absorbing gamma shielding, neutron shielding and the containment vessel.

Observations made from the results of this test included

1. No leaks were detected nor cracks observed on the model.
2. The maximum diametral increase measured on the model was 22.9 percent.
3. The deformation  $\delta/R$  was measured as 0.75 (where  $\delta$  is defined as the diameter of the vessel before impact minus the height of the vessel after impact and  $R$  is the vessel radius before impact).
4. The concrete block was totally demolished.

INTRODUCTION

Future applications of nuclear energy will require the use of a mobile nuclear reactor. One example is the application of nuclear energy to an airplane. This aircraft could stay aloft for long periods of time, provide a long range flight, or have available a large on-board electrical power source.

In all mobile nuclear reactors, fission products must be contained with the same level of confidence as in stationary power plants. An accident of a nuclear powered aircraft can result in impact velocities of 800 to 1000 ft/sec. In addition, the impact direction and type of impact surface are unknown prior to impact.

One method for containing fission products under these severe conditions is to put the reactor in a containment vessel and design the containment vessel and its contents to absorb the impact energy without

rupturing the containment vessel. The energy of impact would be absorbed by deformation of the internal components of the vessel such as the shielding and reactor parts.

Work has been performed at LeRC to determine what materials and design principles can be used to design a reactor-shield-containment vessel system which would enable the containment vessel to withstand high speed impacts without leaking; also, to determine how much containment vessel deformation can be expected during impact, and to predict what impact speeds cause rupture of the containment vessel. Initially, experimental deformation data was correlated by Morris on 3/4- to 4-inch outside diameter hollow vessels (refs. 1 and 2) which had been impact tested to 700 ft/sec. as part of an isotope space program (ref. 3). His correlation predicted that a large reactor containment vessel would deform similar to the small vessels. The correlation, however, did not consider the effects of internal components. Tests were necessary to correlate these effects.

Five 2-foot diameter mock-up models of reactor containment vessel systems were tested (refs. 4 and 5). The models weighed from 350 to 1305 pounds. The first design was simply a hollow vessel to check Morris's correlation which relates small sphere data to larger spheres (refs. 1 and 2). The remaining designs represented a reactor surrounded by radiation shielding and a containment vessel, both of which were designed to absorb impact energy. The tests were conducted at the Sandia Sled Track in Albuquerque, New Mexico. They were impacted at speeds from 241 to 580 ft/sec. No leaks were detected nor cracks observed on any of the models after impact. Also, test data from the first 2-foot diameter hollow vessel design verified that large vessels do deform like small vessels as predicted by the hollow vessel correlation derived from the 3/4- to 4-inch outside diameter vessel data. This lent credibility that the data obtained on 2-foot model tests could be applied to the full scale reactor containment vessels which are of the order of 15 to 20 feet in diameter.

As a result of this program, a new series of impact tests are planned to determine the effect on the containment vessel and reactor core of higher velocities, vessel welds, vessel penetrations, and type of impact surfaces. The models are similar to those formerly tested with an emphasis on different shield and containment vessel materials, and core and containment vessel designs. These models are designed and built at LeRC and tested at the Holloman Track, Alamogordo, New Mexico by the Kirtland Air Force Weapons Laboratory, Albuquerque, New Mexico. Impact velocities to 1000 ft/sec. are planned. Post test evaluation is conducted by both LeRC and the Air Force.

The first test model of this series of tests has been impacted at 640 ft/sec. This report describes the model and test set-up and presents results of the test based on preliminary measurements made at the test site. The model is being measured, sectioned, and analyzed in detail at the LeRC but these results are not yet available.

#### DESCRIPTION OF SLED TEST

The impact test was conducted at the Holloman Track in Alamogordo, New Mexico. This is a dual rail track extending 35 588 feet. Only 2300 feet of the track was used for this test. The test set-up is shown

schematically in figure 1. It consists of a pusher sled, payload sled, sled splitter and target. A bridge frame is placed over the track for mounting some of the camera coverage.

The model is placed on a "payload sled" (ref. fig. 2). It is attached by nylon straps which provide the support during sled operation. A "pusher sled" containing four "Little John" rockets for its propulsion thrust pushes the "payload sled" down the track (ref. fig. 3). Having reached pre-designed speed, the "pusher sled" is stopped by water braking and momentum exchange. It is reused for additional tests. The "payload sled" continues down the track - sustaining HVAR rockets are used to maintain its speed.

A "sled splitter", placed at the end of the track (ref. fig. 4), is designed to separate the impact model from the "payload sled". This massive, 22 000 pound structure is weld fabricated from 3- and 6-inch armored plate. Knives are positioned on the "sled splitter" to cut the nylon support straps and allow the impact model to pass through. The "payload sled" is destroyed with each test by the "sled splitter". Small shape charges are also placed on the "payload sled" to ensure its destruction.

Twenty five feet beyond the "sled splitter" is a concrete block (ref. fig. 5), 5 foot on a side, weighing approximately 18 000 pounds. The impact model, having been separated from the "payload sled", continues a free flight impacting against the concrete block.

Three movie cameras are mounted at the impact point (ref. fig. 6, Fx 2, 3, and 4). They operated at speeds of 4545 and 9090 frames per second. An additional camera was mounted on a bridge over the track looking toward the impact area (Fx 1). This camera operated at 4545 frames per second. Its purpose was to record an overall view including secondary impacts. Additional movies were taken from a helicopter in real time and 250 frames per second showing the entire test sequence.

#### TEST MODEL

A drawing of the model tested is presented in figure 7. It consists of a reactor core mock-up surrounded by shielding and a 2-foot diameter spherical stainless steel containment vessel. The shielding consists of metal saddles (fig. 8) and rock salt. The metal saddles simulate an energy absorbing gamma shield. Rock salt, simulating a LiH neutron shield material, is poured into the 80 percent void spaces provided by the saddles.

The fabrication stages of the core and containment vessel are shown in figures 9(a) to (d). The simulated core consists of an 8-inch diameter by 8-inch long cylinder filled with approximately 850 -  $\frac{1}{4}$ -inch tubes of 0.065-inch wall thickness (fig. 9(c)). This assembly is capped on both ends and placed within a 12-inch diameter spherical stainless steel vessel which simulates the core pressure vessel. The void spaces between the cylindrical core and the spherical vessel are filled with  $\frac{1}{4}$ -inch carbon steel balls as shown in figure 9(b).

This assembly is then centered within the 2-foot diameter containment vessel by small rods which are tack welded to the containment vessel and to the simulated reactor sphere (see fig. 9(d)). The rods are weak and have no effect on the results of the impact test. After completion of the

welding of the containment vessel, saddles and salt are added using the  $1\frac{1}{2}$ -inch pipe fitting.

The tubes in the model core simulate the fuel pins and flow passages of either a fast or thermal reactor core. Both, the 12-inch containment vessel and the  $\frac{1}{4}$ -inch steel balls represent reflector and gamma shielding materials.

The total weight of this model was 1142 pounds (see fig. 7). The core, including the steel balls, tubes, and 1-foot diameter sphere weighed 219 pounds. The saddles and salt weighed 420 and 153 pounds. The outside 2-foot diameter vessel weighed 350 pounds.

### TEST RESULTS

The impact model was slung on the "payload sled" by nylon straps. It was oriented such that the pipe fitting was up-range from the impact point (see fig. 2). Although an attempt was made to ensure that the stripes on the sphere were vertical and horizontal to the impact direction, the difficulty of handling the model while mounted in the straps resulted in some small misalignment. The rocket ignition point was at the 33 280-foot track station. Impact of the sled with the "sled splitter" and subsequent release of the model occurred at the end of the track (35 588-foot station).

Upon impact of the sled with the "sled splitter", the model separates from the nylon sling and passes through the "sled splitter", impacting with the concrete block 25 feet beyond. Figure 5 shows the "sled splitter" and concrete block prior to impact. Shape charges on the "payload sled" initiated destruction of the sled prior to impact but the massive size of the "payload sled" pushed the splitter rearward from its position. The position of the splitter after the test is shown in figure 10. Little damage resulted to the splitter and it does not appear that the movement interfered with the impact of the model.

Impact of the model with the concrete block occurred at a speed of 640 ft/sec. There appeared to be no rotation after its release from the sling. Figures 11(a) to (j) shows a consecutive sequence of photographs of the model at impact with the concrete block. These pictures were taken with camera Fx 3 (9090 frames per second) in figure 6. After the model disappears, a cloud of dust is evident, indicating that the concrete block suffered immediate fracture.

A second series of sequence photographs are shown in figure 12. The camera looked parallel to the path of the sphere at the impact face of the concrete block. These pictures were taken with camera Fx 1 (4545 frames per second) in figure 6.

After impact, the model was found lying on the cutter of the splitter (see fig. 13). It was assumed that the splitter was pushed back against the mound of dirt supporting the concrete block after the impact and the model slid back down through the tunnel of the splitter coming to rest in the position shown. The concrete block was totally destroyed (see fig. 14). There was no rebound velocity observed when the model impacted the concrete block.

Photographs of the impacted model are shown in figures 15(a) to (c). Deformation occurred in both, the impacted hemisphere and the hemisphere away from the direction of impact. The flat impact face is not parallel to the weld because the unit was not oriented in the sling with the weld

perpendicular to the direction of impact. The paint and location identification numbers also remained only on a small portion of the sphere. The remainder came off at impact. Up to the point of impact, however, the paint remained on the unit.

A preliminary leak test was performed by pressurizing the sphere with nitrogen and sealing off the lines. The pressure was then monitored over a period of 30 minutes. No leaks were detected. More exact leak checks will be made when the vessel is returned to the Lewis Research Center.

Preliminary measurements were taken of the sphere. These measurements indicate how much strain occurred. The maximum diameter occurred at the impacted face. It was measured as  $29\frac{1}{2}$  inches compared to 24 inches prior to impact. This is a diametral increase of 22.9 percent. It is of the same magnitude as the Metal-Shield model which was tested at the Sandia Track (ref. 5, fig. 12). This model contained water and saddles as a shield material impacting at 467 ft/sec. The amount of deformation  $\delta/R$  was measured as 0.75 (where  $\delta$  is defined as the diameter of the vessel before impact minus the height of the vessel after impact and  $R$  is the vessel radius before impact). This also compares with the Metal-Shield model described in reference 5.

When the test model is returned to the LeRC, further measurements will be taken to more accurately evaluate the deformation and strain that occurred on the unit. Test specimens will be machined and pull tests made. The simulated core will be sectioned and the deformation of the simulated fuel pins will be analyzed.

## CONCLUSIONS

This report presents data of an impact test conducted on a 2-foot diameter mock-up model of a reactor containment vessel system. The test was conducted at the Holloman Test Track in Alamogordo, New Mexico. The model weighed 1142 pounds. It was impacted against an 18 000 pound concrete block at 640 ft/sec. The following observations were made from the results of this test:

1. No leaks were detected nor cracks observed on the model.
2. The concrete block, weighing 18 000 pounds, was totally destroyed at impact.
3. There was no rebound velocity observed when the model impacted the concrete block.
4. The maximum diametral increase measured on the model was 22.9 percent.
5. The deformation  $\delta/R$  was measured as 0.75 (where  $\delta$  is defined as the diameter of the vessel before impact minus the height of the vessel after impact and  $R$  is the vessel radius before impact).

## REFERENCES

1. Morris, Richard E.: Permanent Impact Defeformation of Spherical Shells. NASA TM X-2067, 1970.
2. Morris, Richard E.: Empirical Correlation of Small Hollow Sphere Impact Failure Data Using Dimensional Analysis. NASA TM X-52874, 1970.
3. Simonis, J. C.; and Stoneking, C. E.: A Study of Impact Effects of Spherical Shells. Part II: A Theoretical and Experimental Study of the Response of Spherical Shells to Impact Loads. Rep. SC-CR-67-2540, Sandia Labs., Dec. 1966.
4. Puthoff, R. L.; and Dallas, T.: Preliminary Results on 400 fpc Impact Tests of Two 2-ft Diameter Containment Models for Mobile Nuclear Reactors. NASA TM X-52915, 1970.
5. Puthoff, R. L.: High Speed Impact Tests of a Model Nuclear Reactor Containment Systems. Presented at the Am. Nucl. Soc. Annual Meeting, Boston, Mass., June 13-17, 1971.

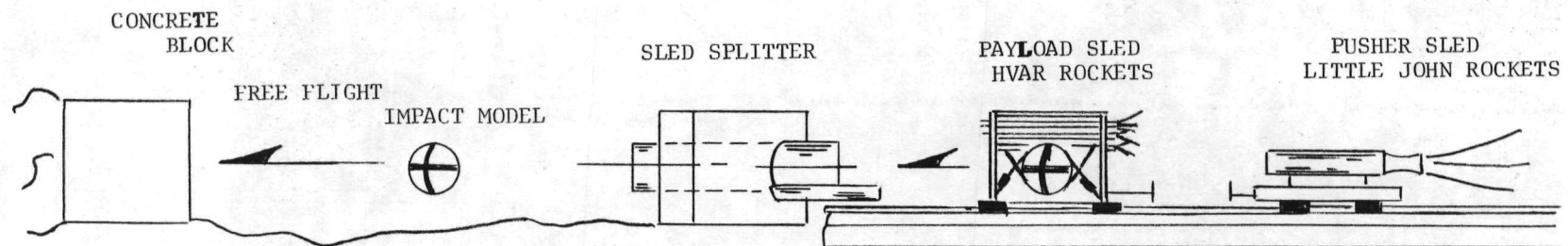


Figure 1: Rocket Sled Test Set-Up

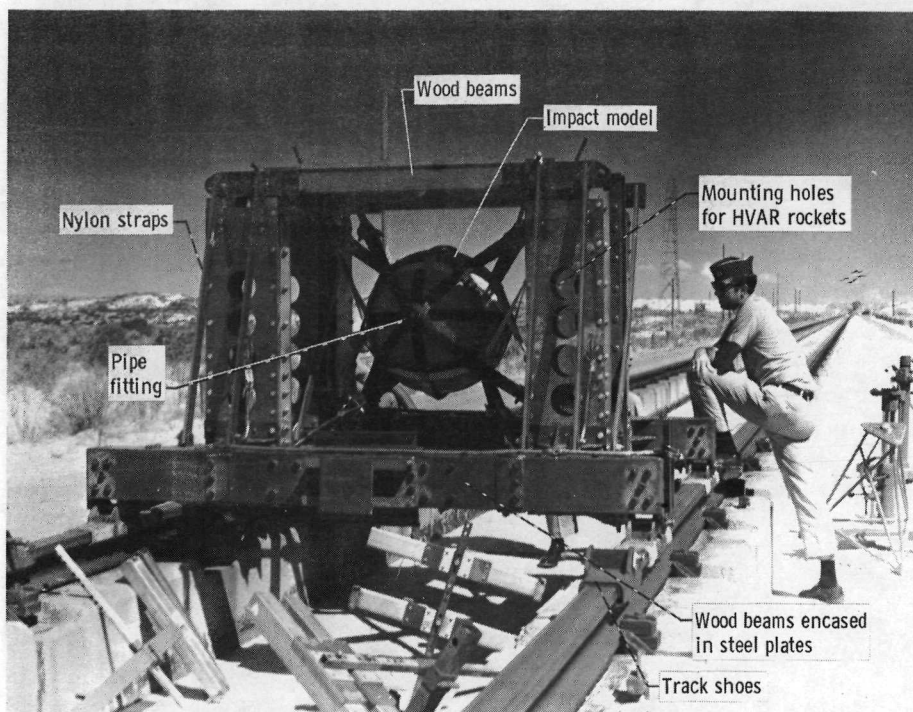


Figure 2. - Payload sled.

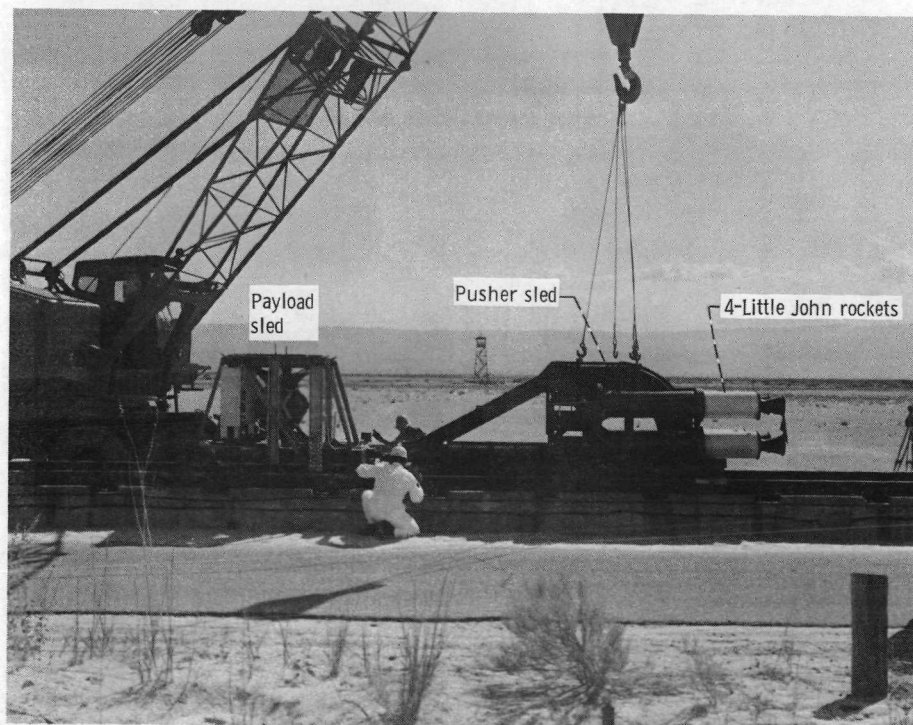


Figure 3. - Pusher sled.

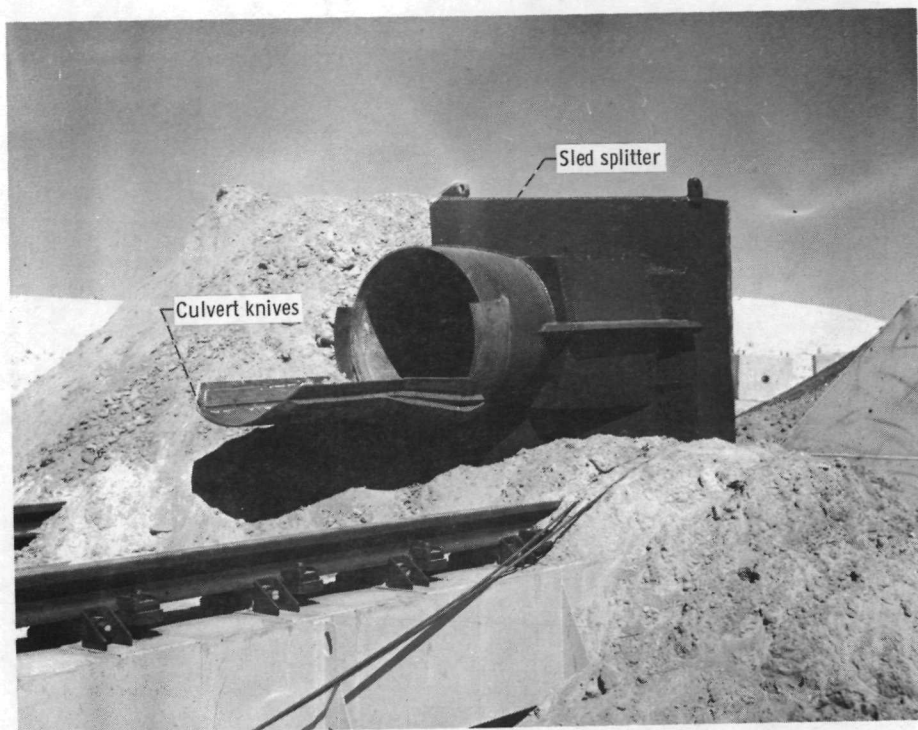


Figure 4. - Sled splitter at end of track.

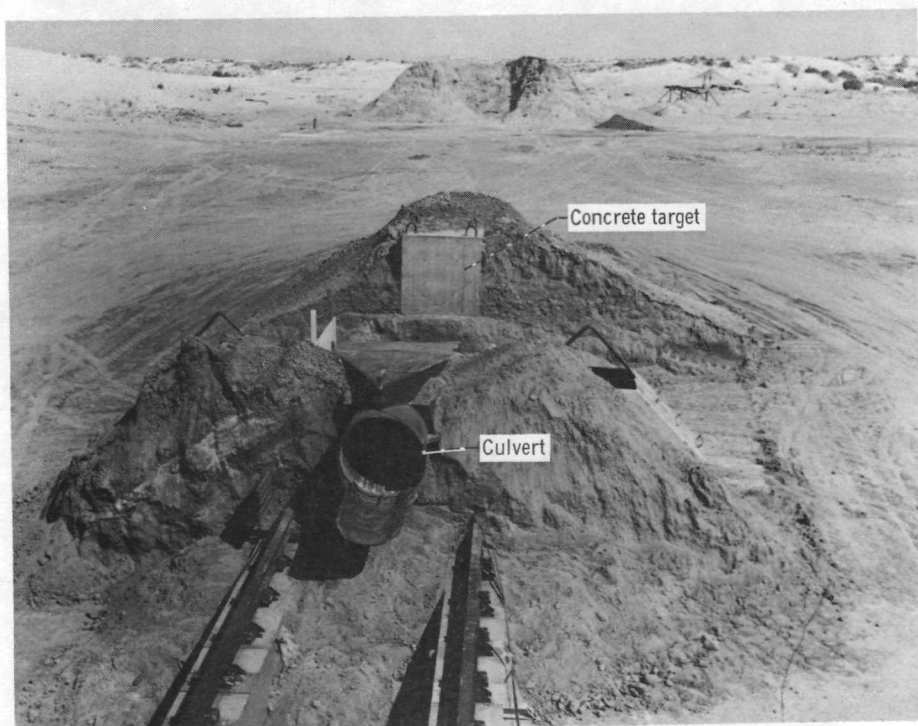


Figure 5. - Sled splitter and concrete target.

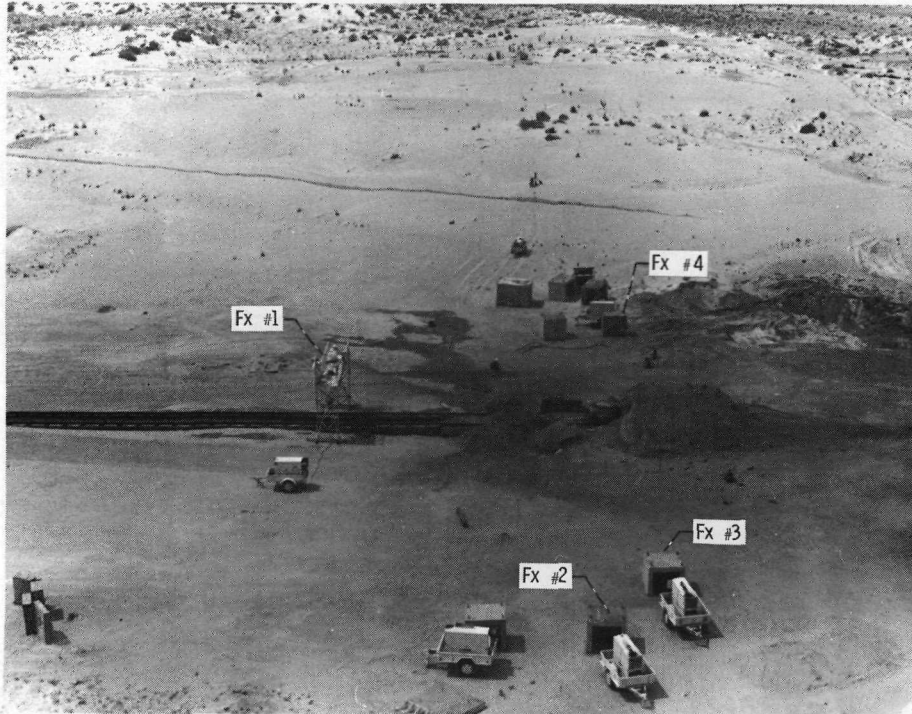


Figure 6. - Movie camera location.

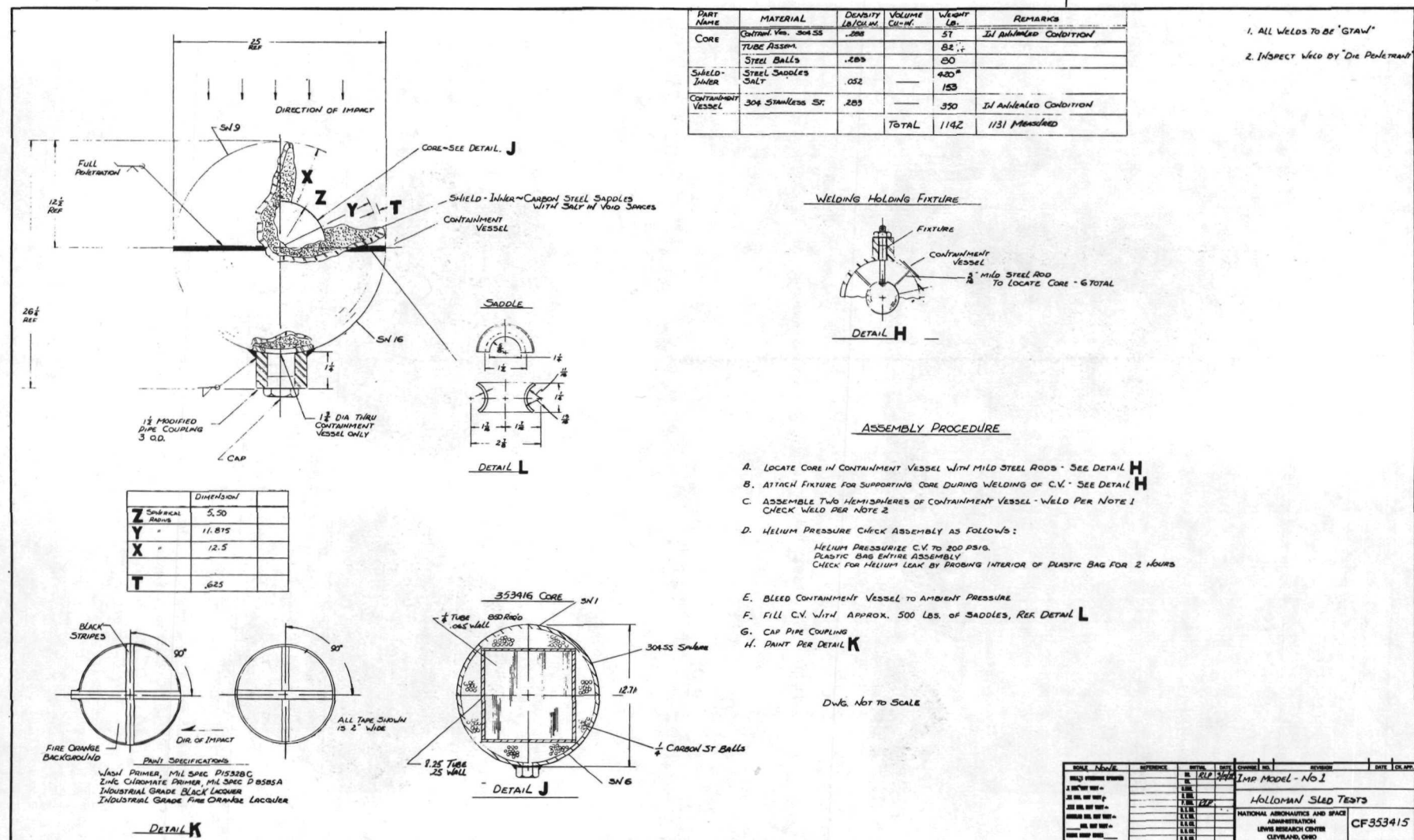


Figure 7. - Impact Model 353415 ( #1).

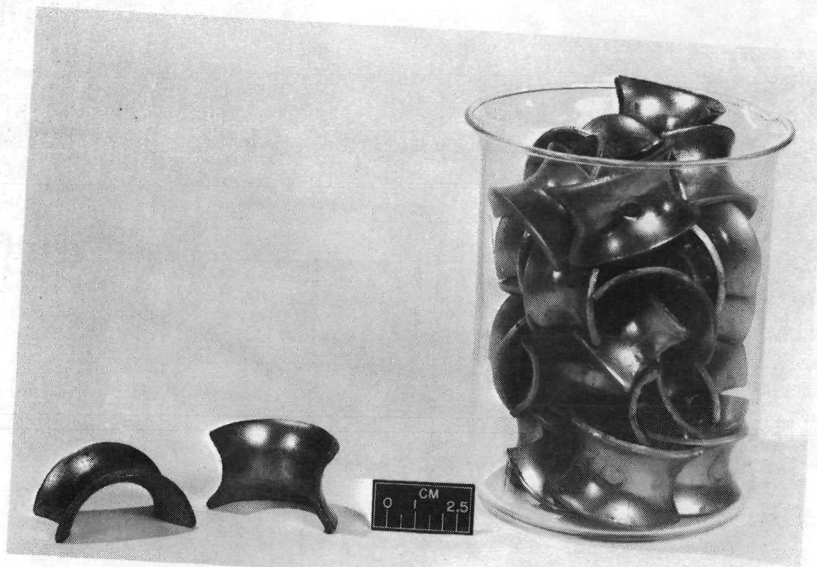


Figure 8. - Steel saddles which simulate gamma shield material.

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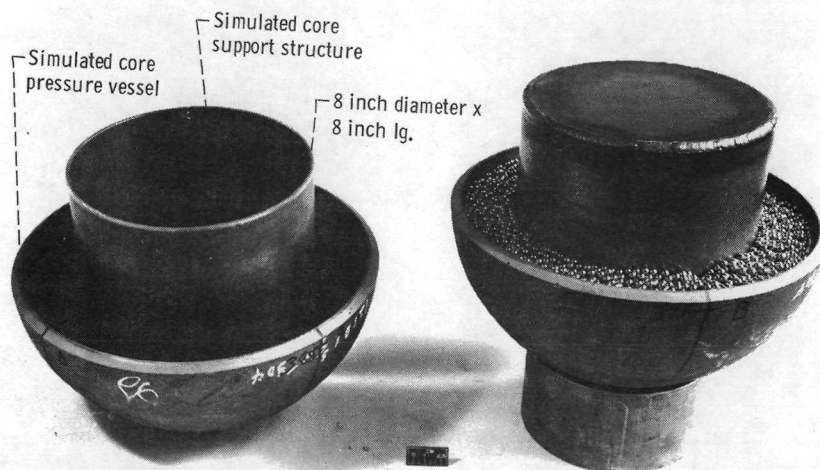
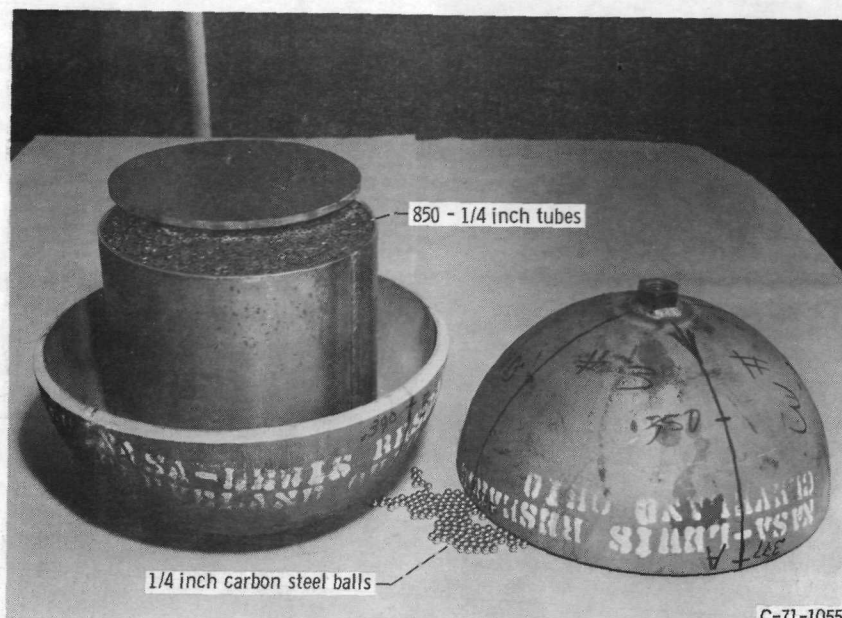


Figure 9(a). - 8 inch diameter core cylinder welded into 12 inch diameter simulated pressure vessel.

Figure 9(b). - End cap assembled - 1/4 inch balls in lower shell.

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Figure 9(c). - Core showing bundle of 850 tubes.



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Figure 9(d). - Core centered in containment vessel.



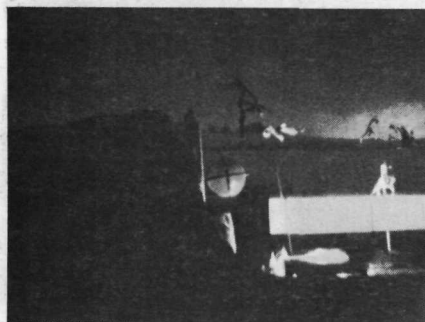
Figure 10. - Sled splitter - post impact.



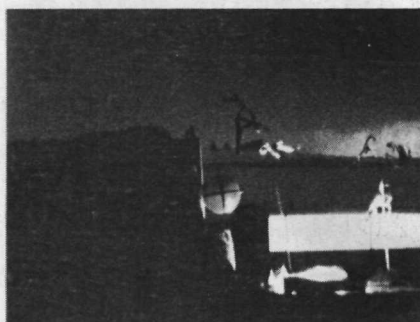
(A)



(B)



(C)



(D)

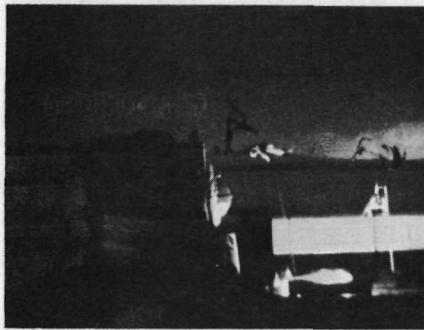


(E)



(F)

Figure 11 (a-j). - Sequence photographs of impact.



(G)



(H)



(I)



(J)

Figure 11. - Concluded.



(A)



(B)



(C)



(D)



(E)



(F)

Figure 12 (a-f). - Sequence photographs showing the sphere parallel to the direction of impact.

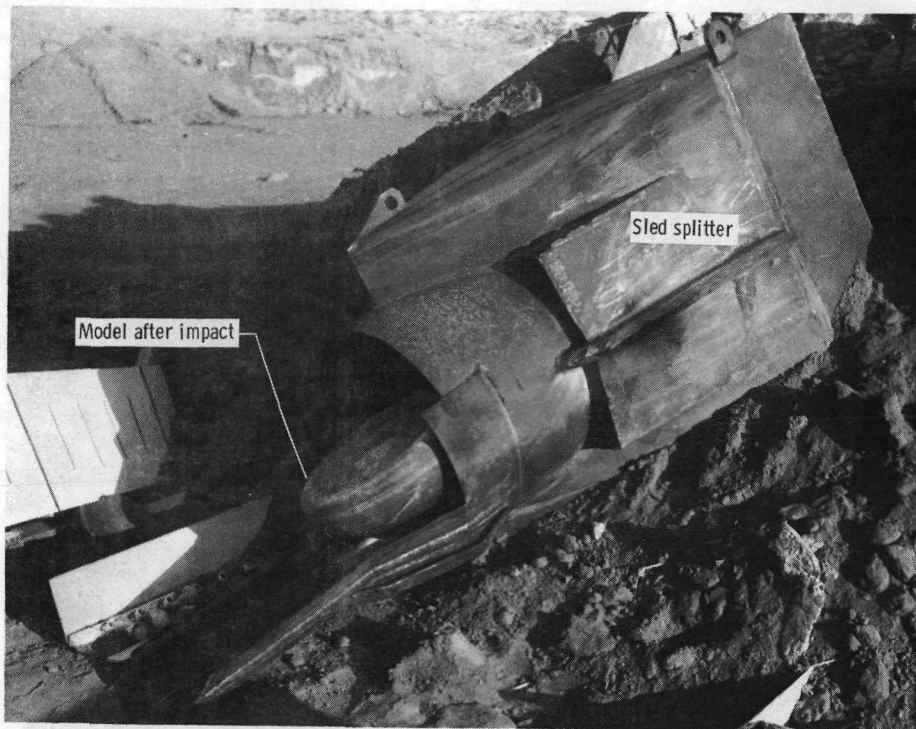


Figure 13. - Model location after impact.



Figure 14. - Concrete target - post impact.



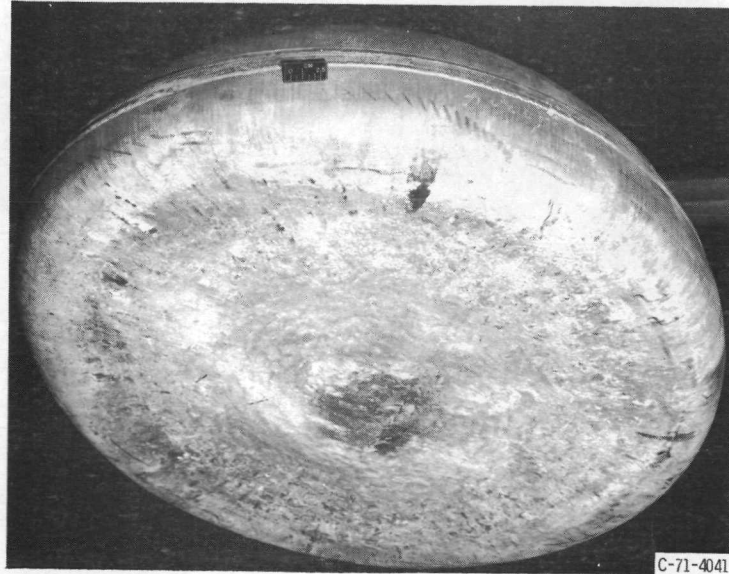
(a)

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(b)

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(c)

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Figure 15. - Model - post impact.